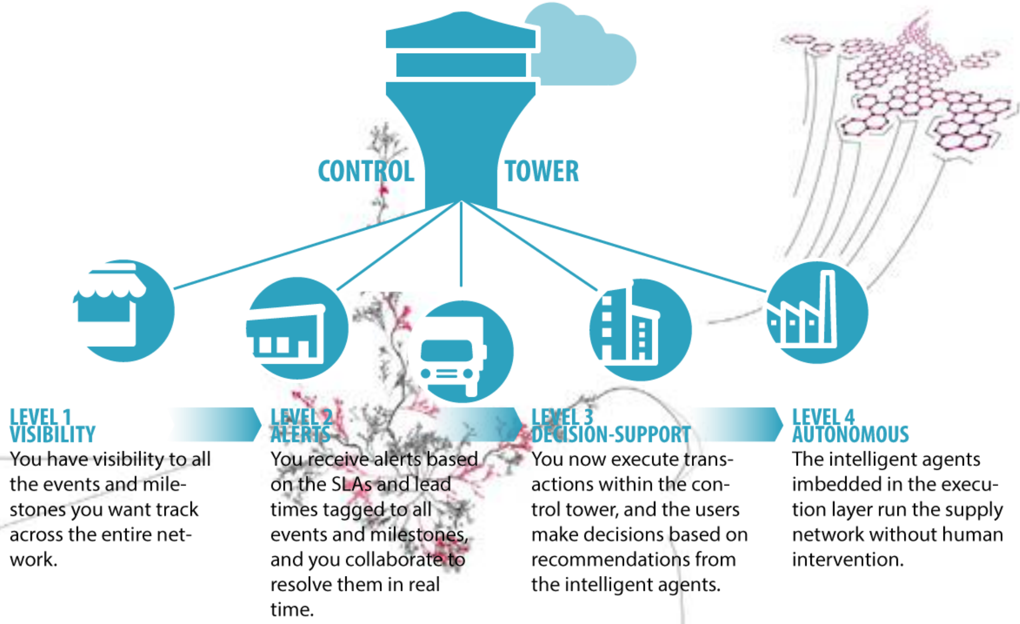
USING INFORMATION FOR PLANNING SPARE PARTS



ENGIN TOPAN

UNIVERSITY OF TWENTE

E.TOPAN@UTWENTE.NL

UNIVERSITY OF TWENTE.

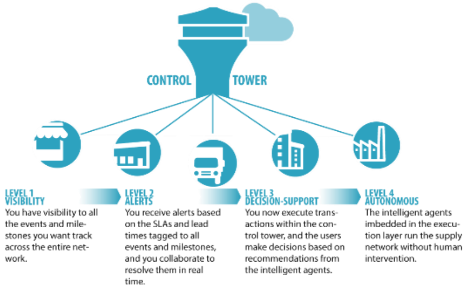
WHO AM I?

OUTLINE

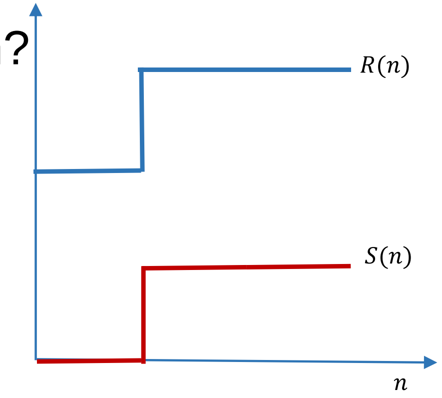
- Why is information important in supply chains?

- Role of control towers

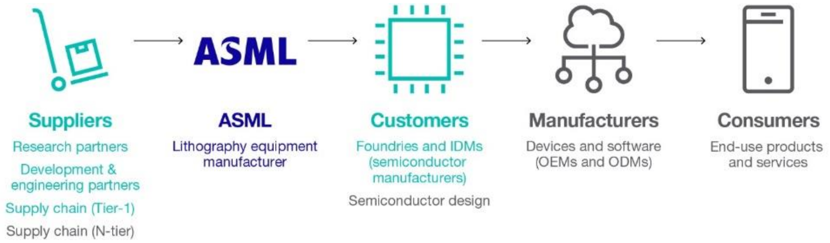
  - A survey on service control towers for spare parts



- Can we use condition information for spare parts?
  - Advance Demand Information: What is the benefit? How does a smart planning look like?
  - Advance Supply Information: Same story but can we use it for alert generation?



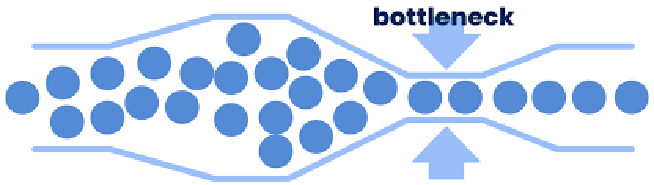
- Future of using information



WHY DATA DRIVEN PLANNING?

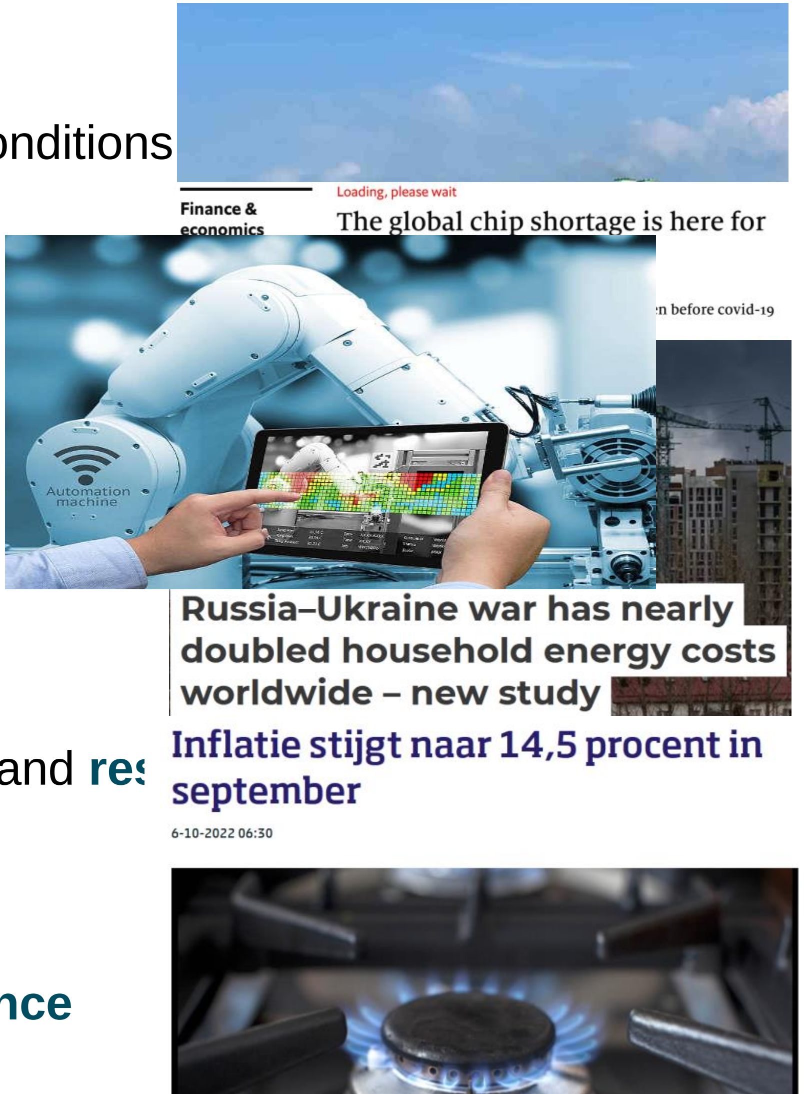
- **Lean** and **efficient** supply chains
  - Also **fragile**, **not flexible / resilient** against dynamic market conditions

- Evergreen just an example ➔ many **bottlenecks**
  - **Impact** on **society**
    - ➔ **Global chip crisis**
    - ➔ **Energy crisis**
    - ➔ **Inflation**



- Lack **resilience** or **agility**: **flexible** capacity to **anticipate**, **adapt** and **res**

- Paradigm shift: **Disruptive** solutions
  - use **data**, **predictive adaptive control** to be **flexibility/resilience**



CONTROL TOWERS

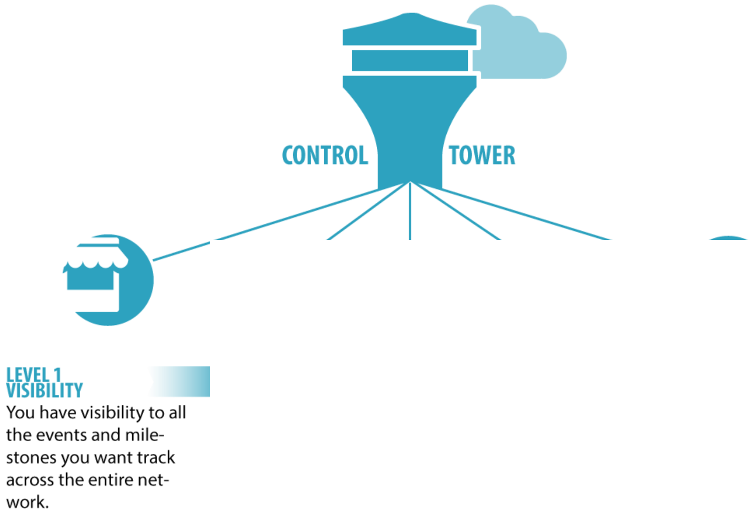
- **Supply chain control towers (SCT)**
  - **real-time data** to **control/integrate** processes in the **supply chain**

  1) monitor SC

  2) signals deviations from plans

  3) suggestions / advices to human

  4) decisions without human interventions



Predictive Analytics (predict) **Forecasting Statistics Machine Learning** → **Prescriptive Analytics** (decide) **Optimization Reinforce. Learning**

- **Model based (Optimization & Math) + Data driven (AI)**

SPARE PARTS CONTROL TOWERS

TOPAN ET AL. (2020): SURVEY

- **Five OEMs** participated in our review, abbreviated *A*, *B*, *C*, *D*, and *E*

- **A** : an **IT** company hardware and telecommunication devices
- **B** : **semiconductor** industry
- **C** *:* **aerospace** industry
- **D** : **defense** and security applications
- **E** : **material handling** systems

- *The five* have a strong market position/market leader with close ties with their customers

CONTROL TOWERS? FOR SPARE PARTS

TOPAN ET AL. (2020): SURVEY

- Mostly SC networks with **2-4 echelons?**
- Mostly **slow moving** and **expensive parts**
- Operational planning requires significant effort **(40-90% of the planning team)**

Service structure (current situation)	OEMs				
	A	B	C	D	E
Number of product types	Many (> 1000)	Medium (100-1000)	Many (> 1000)	Few (customized) (< 100)	Medium (customized) (100-1000)
Number of installed bases / Number of customers	Very many (> 10000) / Many (> 1000)	Many (> 1000) / Few (< 100)	Medium (100-1000) / Medium (100-1000)	Few (< 100) / Few (< 100)	Many (> 1000) / Many (> 750)
Number of customers / Type of customers	Many (> 1000) / B2B and B2C	Few (100-1000) / B2B	Few (100-1000) / B2B	Very few (< 100) / B2G	Many (> 1000) / B2B
Number of echelons / Number of warehouses	3-4 echelons / 3 CWs, hundreds of LWs	2-3 echelons / 1 CW, < 50 LWs	2-echelon / 1 CW, < 20 LWs	2 echelon / 1CW, 4 assets as depot	1 echelon / 1CW
Carries out maintenance? / Operates repair shops?	Yes / Yes (as a separate entity)	Yes, onsite / No	No / Yes	No / Yes	Yes, onsite / No
Parts planning: LRU and or SRU/ Number of SKUs	LRU / Many (>10000)	LRU / Medium (1000-10000)	LRU and SRU / Many (> 10000)	LRU and SRU / Medium (1000-10000)	LRU / Medium (1000-10000)
Part characteristics (demand vs price)	All sorts of demand rates and prices	Mostly slow moving (<5 per year) and expensive (> 1000€)	All sorts of demand rates and expensive (> 1000€)	Mostly slow moving (<5 per year) and expensive (> 1000€)	All sorts of demand rates, typically cheap (<100€)
Workforce among operational and tactical planning	Operational: 40% FTEs Tactical: 60% FTEs	Operational: 70% FTEs Tactical: 30% FTEs	Operational: 67% FTEs Tactical: 33% FTEs	Operational: 60-90% FTEs Tactical: 40-10% FTEs	Operational: 90% FTEs Tactical: 10% FTEs

CONTROL TOWERS FOR SPARE PARTS – INFORMATION

TOPAN ET AL. (2020): SURVEY

Supply and Demand Information Use and Control	OEMs				
	A	**B**	**C**	**D**	**E**
Getting status update about the external supply (your suppliers') process	3	3	3	2	2
Having control over external supply process	2	2	2	1	1
Having prediction models/demand forecasts	3	3	3	2	3
Using prediction models/forecast in planning operations interventions	3	2	3	1	3

- *The five* all have **information** about their **external supply process**. Yet, they have **limited** or **no control** over their **supply process**.
  - They **often do not use supply** information

- Four of *the five* use **demand forecasts** for operational interventions.

  ➔ **Machine learning is a powerful tool here!**

CONTROL TOWERS FOR SPARE PARTS – INFORMATION

TOPAN ET AL. (2020): SURVEY

Elements	**OEMs**				
	A	**B**	**C**	**D**	**E**
Optimization methods for decision problems	Simple decision rules	Simple decision rules	Simple decision rules	Manual / Simple decision rules (depending on service contracts)	NA
Demand and supply model	Mix of deterministic and stochastic	Mix of deterministic and stochastic	Mix of deterministic and stochastic	Deterministic	NA
Planning horizon	Finite	Finite	Finite	Infinite / Finite (depending on service contracts)	NA

- Operational planning problems are solved by using either **simple rules (ad-hoc thresholds)** or made manually based on **expert knowledge**.

- **Deterministic? demand and supply models** are widely used. The uncertainty of demand and supply, which is crucial in estimating downtime risk, is often neglected.

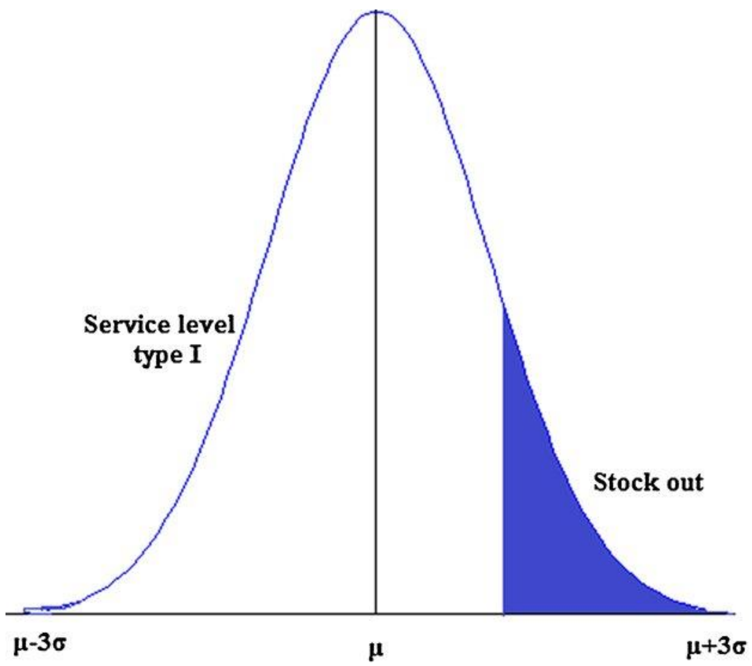
ADVANCED DEMAND INFORMATION

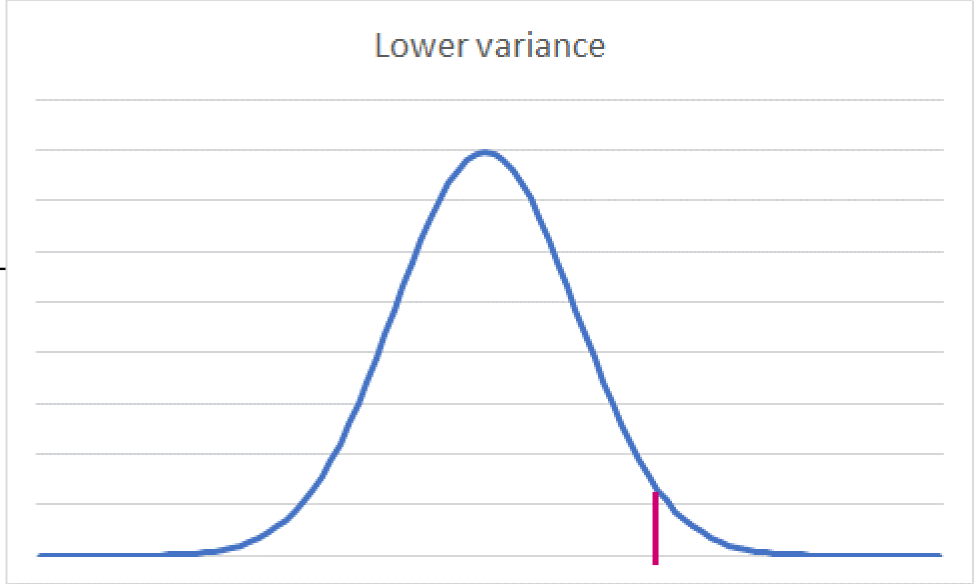
TOPAN ET AL. (2024): ADI FOR SPARE PARTS

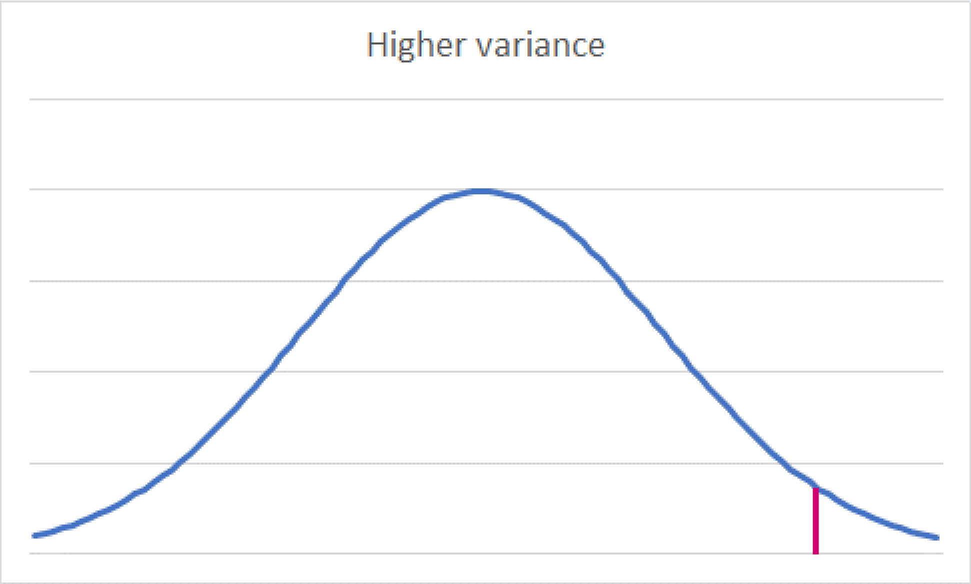
- **ASML**, a world-leading manufacturer of lithography systems
- **Uptime** of these systems is critical importance for users/customers.
- Keep **spare parts**, operate a global **inventory network** with local warehouses close to customers.
- Spare parts are very **expensive** and **slow moving**
  - Price: >50000 Euros, Demand: 1 per 2 years
- Keep inventories at a minimum level, **zero** if possible.

ONE PREDICTIVE CONTROL

HOLDING INVENTORY



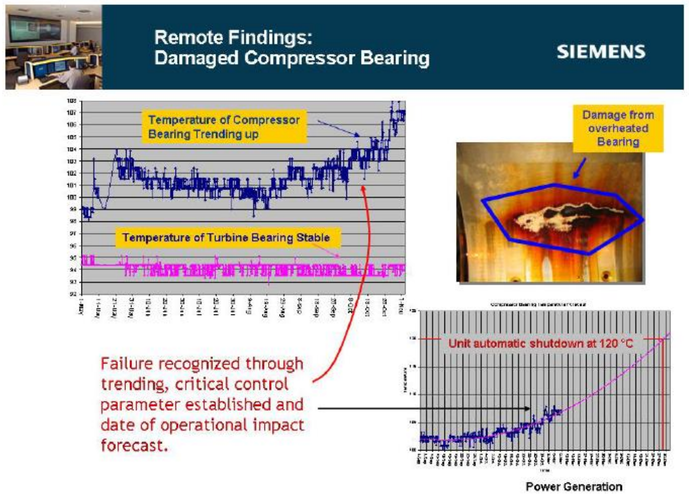




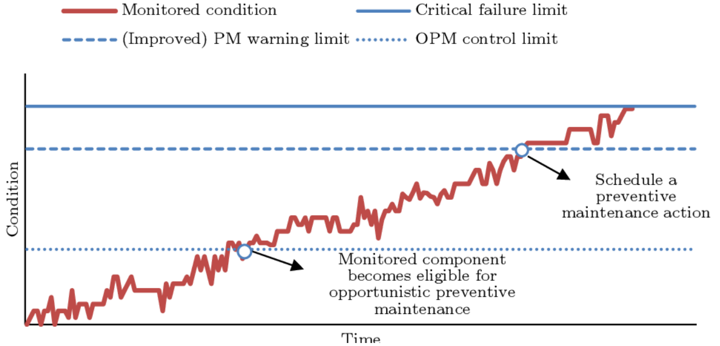
Do you see ways to **reduce demand / supply uncertainty using demand info?**

ADVANCED DEMAND INFORMATION
CONDITION MONITORING DATA

- ASML / OEMs install **condition monitoring** systems installed at their customers
  - Sensors
  - Data
  - Prediction models to predict failures and to produce **signals/alerts**



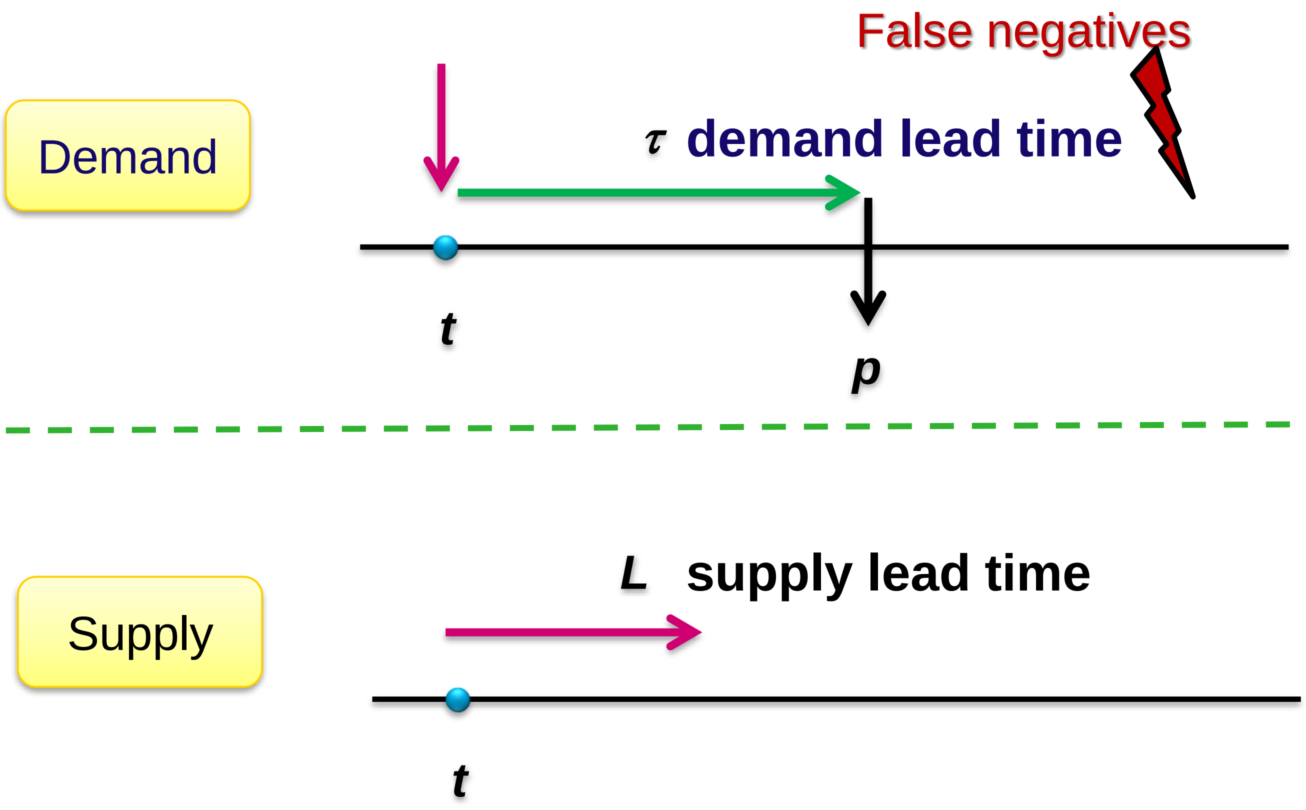
- This information is collected and used for maintenance planning



- But can we use these signals as **demand signals/alerts** in planning spare parts supply? **ADI?**

- If so, how does a predictive adaptive **smart** control **policy** look like?

IMPERPECT ADVANCE DEMAND INFO



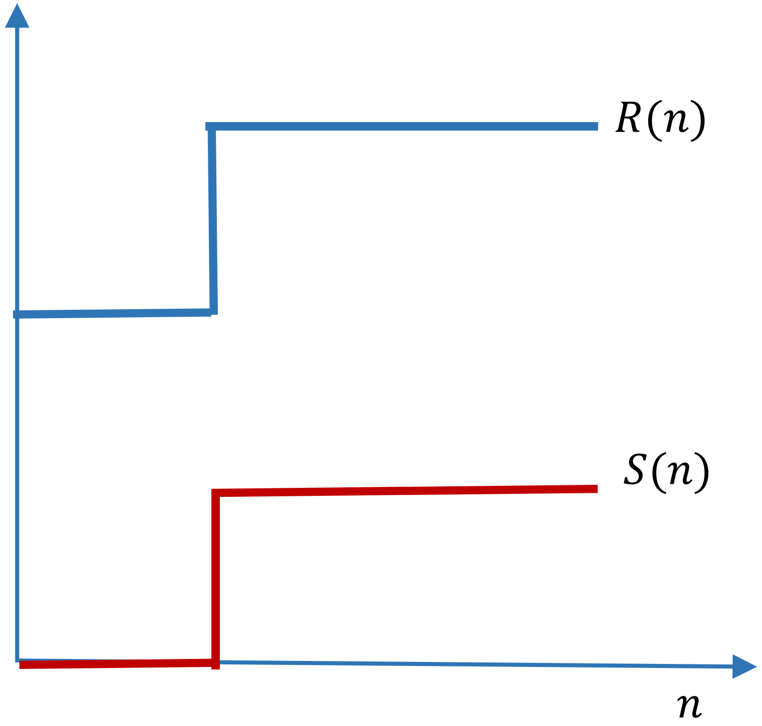
- ***p*: probability that a signal will ever become a demand realization** **precision (reliability, accuracy)** $\frac{TP_i}{TP_i + \boldsymbol{FP_i}}$
- $\boldsymbol{\tau}$ **: interval** or **random duration (geometric distr.)** signal stays in the system
- ***q*** **:** ratio of predicted demand to total demand **recall (sensitivity)** $\frac{TP_i}{TP_i + \boldsymbol{FN_i}}$

10 signals, 10 turn out to be a failure ➔ p is 1 ☺
10 failures detected, 100 failures ➔ q = 0.1 ☹

IMPERPECT ADVANCE DEMAND INFO

STATE DEPENDENT TWO-SIDED POLICY

- Optimal policy is a **state-dependent two-sided base-stock policy** for items with ADI.



- ***R(n)*: return-down-to** level
- ***S(n)*: order-up-to** level
- depends **on *n* (number of signals)** + **pipeline**

- **For slow movers ➔ keep stock** when there is a **demand signal** and **return** it if it disappears ?

IMPERPECT ADVANCE DEMAND INFO

VALUE OF IMPERFECT ADI

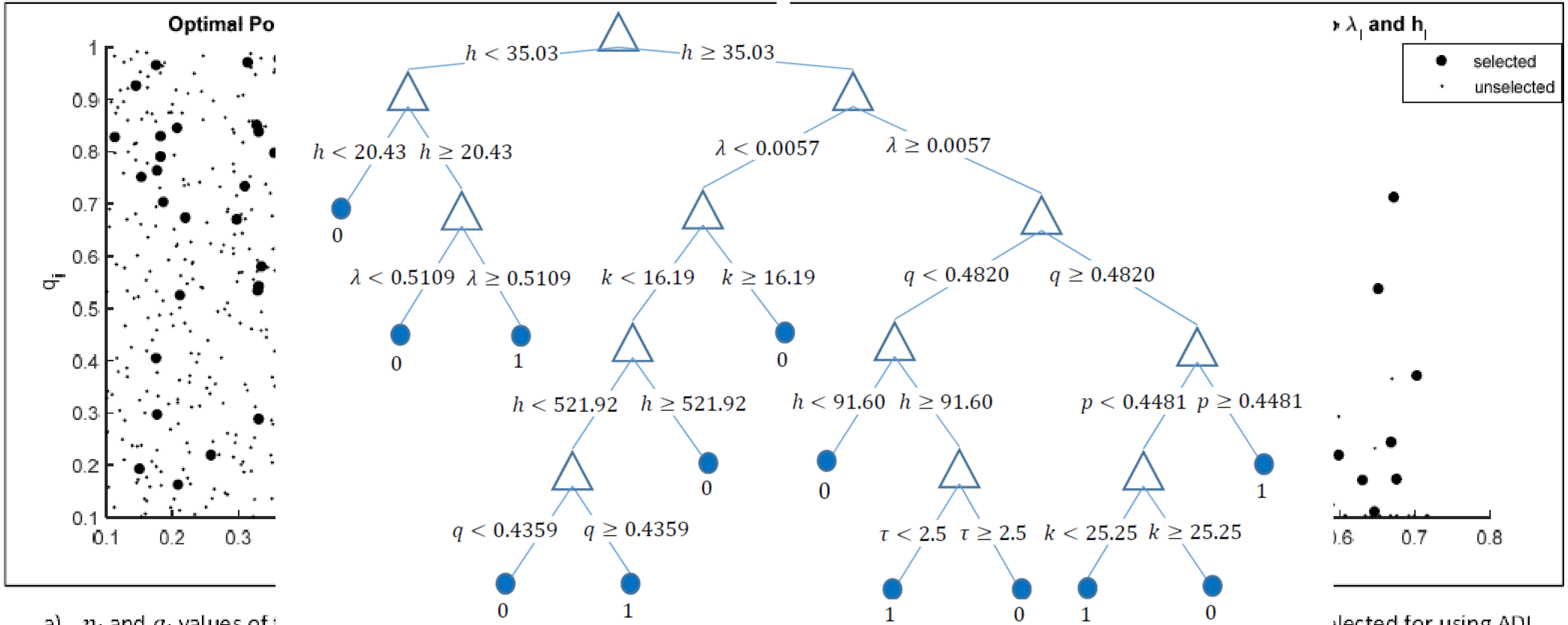
Part	h (€/unit/week)	$[\tau_l, \tau_u]$ (week)	λ (unit/week)	p	q	c_r	g_{NoADI} (€/week)	g_{ADINR} (€/week)	g_{ADI} (€/week)	PCR_{ADINR}	PCR_{ADI}
P	2720	[2,6]	0.0188	0.42	0.44	5500	1406.01	1399.69	963.05	0.45%	31.50%
T	112	[8,12]	0.0600	0.90	0.90	325	248.13	144.37	137.03	41.82%	44.78%
X	152	[0,4]	0.0019	0.45	0.43	400	145.57	142.05	134.47	2.42%	7.63%
W	646	[0,1]	0.0036	0.90	0.50	1400	274.28	274.28	274.28	0.00%	0.00%

- Imperfect ADI yields **substantial savings**
- **Timing** of ADI is highly influential on the value of ADI (Demand lead time > Supply lead time)
- **Keep inventory** when there is a **demand signal**, if there is **no signal don’t keep** inventory and **return** it back to the **central warehouse**

IMPERPECT ADVANCE DEMAND INFO

WHICH ITEMS SHOULD WE MONITOR?

- **Imperfectness** (p,q) is important but **logistics-related parameters** (demand rate, cost price, penalty cost, lead time) are also very important.



a) p_i and q_i values of

elected for using ADI

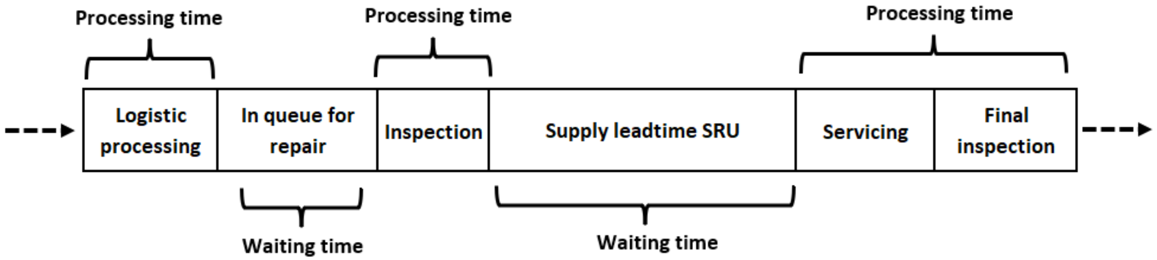
ADVANCE SUPPLY INFO =?

ALIZADEH ET AL. (2022)

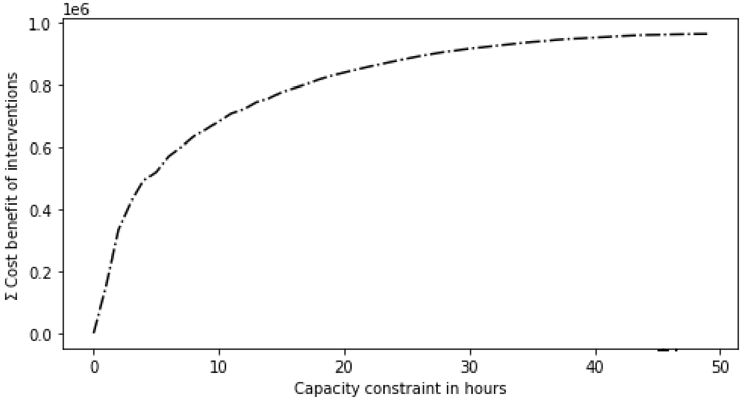


- Alert systems generate **too many exception messages**, e.g., on average **300 -2000 alerts** per week.

- **Using advance supply information** to plan operational interventions **proactively**.



- **Data-driven method (neural networks)** + **model-based approach (probabilistic model)** to support **human planners** by generating alerts when a supply delay is identified.



- We improve the **accuracy of repair time predictions up to 14%** **reduce intervention costs by 13%**.

Do you **monitor supply?**

FAILURE / USAGE RATE INFO AS DEMAND INFO
FAILURE RATE

- T: first time to failure given that a system (first time) is on operation at time 0
- Cumulative probability distribution: F(t)=P(T≤t)
- Probability density of first failure: f(t)=F'(t)
- **Reliability (Survival) function**: $R(t) = \bar{F}(t) = 1 - F(t)$
- **Failure rate**:

$$\boxed{z(t) = f(t)/R(t)}$$

$$z(t) \approx \frac{P\{T \leq t + \Delta t | T > t\}}{\Delta t}$$

- **Failure rate** is a key/major input for finding the optimal stock levels

  ➔ **usage rate or demand rate** λ

FAILURE RATE

FMECA

Another approach is to forecast usage by using **installed base information** or calculate/collect **ASML's reliability database**.

FAILURE MODES AND EFFECTS ANALYSIS – WORKSHEET

SYSTEM Automatic washing machine | SUBSYSTEM Water | ASSEMBLY Tank

Item	*Ref. No.*	*Code No.*	*Function*	*Failure mode*	*Failure mode frequency* (α)	*Failure rate* (10^6 *hrs*) (λ)	*Failure effect* – *Immediate level**	*Failure effect* – *Next level*†	*Symptoms*	*Severity level* (S)	*Criticality* (C) ($=\alpha\lambda S$)	*Remarks and total criticality for each item*
1	2	3	4	5	6	7	8	9	10	11	12	13
Tank	T	TA1/4	Hold water	Warp	0.3	0.05	Possibly foul moving parts		Noise	0.7	0.01	
				Leak	0.4				Wet floor	0.7	0.014	
				Burst	0.25		Catastrophic			1.0	0.013	Total 0.037
Hot water pipe	P1	Cu/1/2		Warp	0.5		May impede flow		Fills slowly	0.1	0.005	
				Leak	0.4	0.1			Wet floor	0.7	0.028	
				Burst	0.05		Catastrophic			0.1	0.005	Total 0.038
Cold water pipe	F2	Cu/1/2		Warp	0.3				Fills slowly	0.1	0.002	
				Leak	0.6	0.05	As above		Wet floor	0.7	0.021	
				Burst	0.05					1.0	0.002	Total 0.025
Hot water valve	V1	V124	Control flow of hot water	Leak	0.3				Wet floor	0.7	0.21	
				Burst	0.05	1.0	Catastrophic			1.0	0.05	
				Seizes shut	0.5		No hot water	Cold wash	As 8	0.4	0.2	
				Seizes open	0.1		Overflow			1.0	0.1	0.56
Cold water valve	V2	V124	Controls cold water	Leak	0.3					0.7	0.21	
				Burst	0.03		Catastrophic			1.0	0.05	No cold water
				Seizes shut	0.5	1.0	No cold water			1.0	0.5	Could ruin clothes
				Seizes open	0.1		overflow			1.0	0.1	Total 0.86
Hot and cold connectors (two in series)	C1	CCu/1/2		Leak	0.6	0.1			Wet floor	0.7	0.041	0.077 each
	C2	Ccu/1/2		Burst	0.3		Catastrophic			1.0	0.03	0.144 together
Drain pipe to pump	P5	Cu/1/2	Carries water away	Leak	0.5					0.2	0.035	
				Burst	0.3	0.1	Catstrophic			0.1	0.03	0.066
				Warp	0.1		May impede flow		Empties slowly	0.1	0.001	
Drain connection	C5	Ccu/1/2		Leak	0.9	1.0			Wet floor	0.7	0.63	0.73
				Burst	0.1		Catastrophic			1.0	0.1	
Seal	S2	S/R/15		Leak	1.0	0.1				0.6	0.16	0.16
Door	D	D/128		Warp	0.85	0.1	May leak			0.7	0.06	
				Break	0.1		Flood			1.0	0.01	0.07

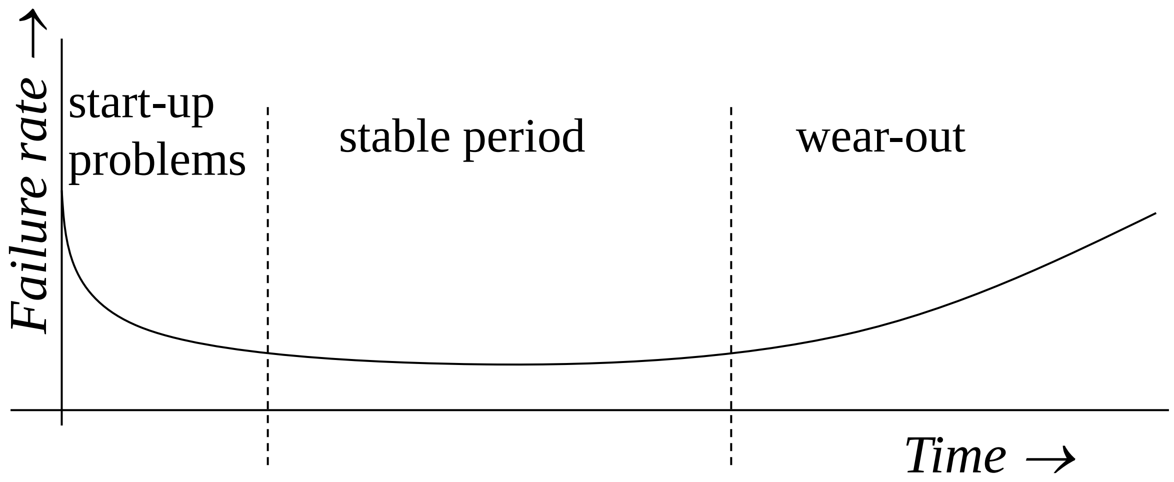
* Immediate level for this analysis *Assembly*

† Next level for this analysis *Sub-system*

Total criticality 2.69

FAILURE RATE AS DEMAND INFO

BATHTUB CURVE?



- **start-up (infant mortality):** z(t) decreasing in t (DFR=Decreasing Failure Rate)
- **stable period (neutral):** z(t)=a (constant)
- **wear out: z(t) increasing in t** (IFR=Increasing Failure Rate)

Failure (usage) rate is changing with aging of the systems

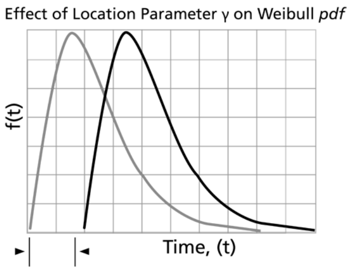
FAILURE RATE AS DEMAND INFO

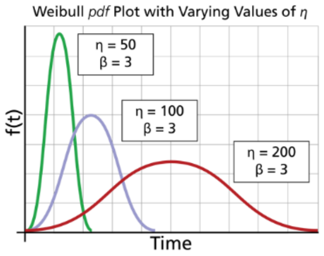
WEIBULL DISTRIBUTION?

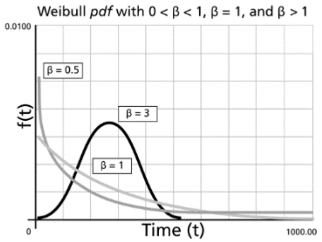
- **Reliability function $R(t)$:**

$$\bar{F}(t)=\begin{cases}1 & 0<t\le t_0\\ e^{-\left(\frac{t-t_0}{\eta}\right)^{\beta}} & t>t_0\end{cases}$$

- Interpretation of parameters:
  - t_0= failure free period (location parameter)
  - η = scale parameter of life time:
  - β = shape parameter; β=1: (shifted) exponential distribution







FAILURES AS DEMAND INFO

WEIBULL DISTRIBUTION

- **Failure rate function:**

$$z(t) = \frac{f(t)}{R(t)} = -\frac{R'(t)}{R(t)} = \frac{\beta}{\eta}\left(\frac{t - t_0}{\eta}\right)^{\beta-1}$$

- **β=1 ➔** constant failure rate: z (t)=λ (constant), $F(t) = 1 - e^{-\lambda t}$ (Weibull with β=1 and t0=0)

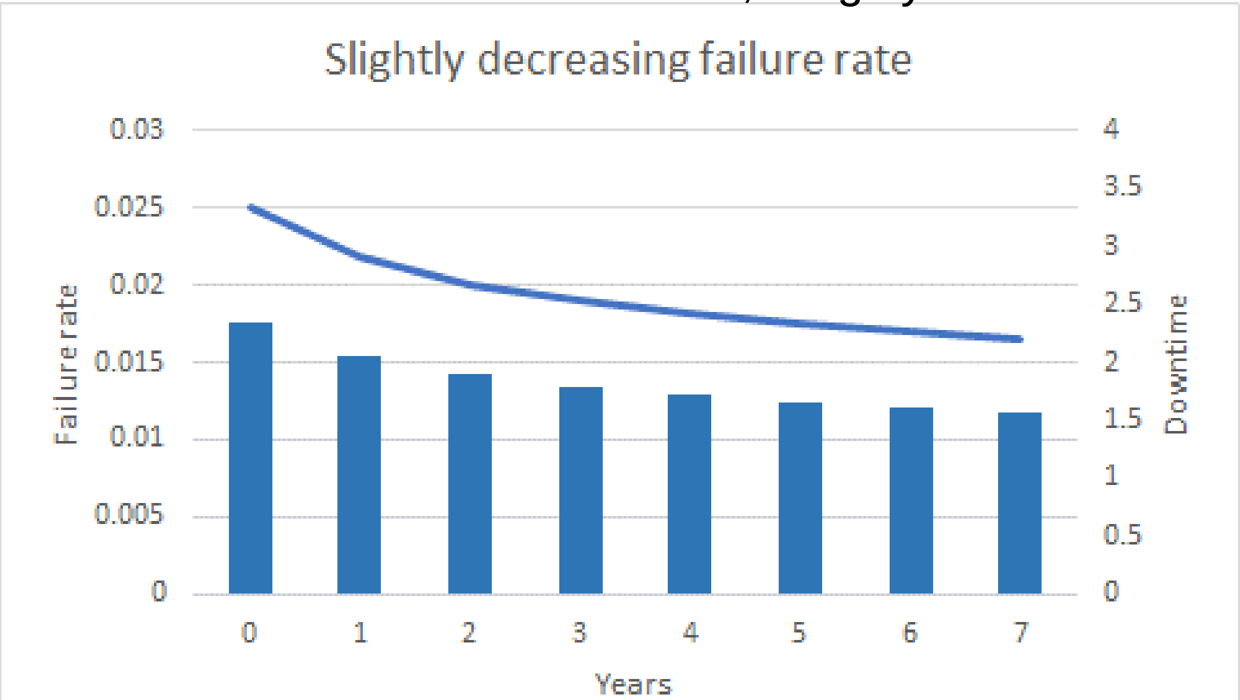
- **β>1 ➔** wear out: z (t) is an increasing function of the time t: Increasing Failure Rate (IFR)

- **β<1 ➔** running in: z (t) is a decreasing function of the time t: Decreasing Failure rate (DFR)

EXAMPLE A VERY EXPENSIVE SLOW-MOVING SKU

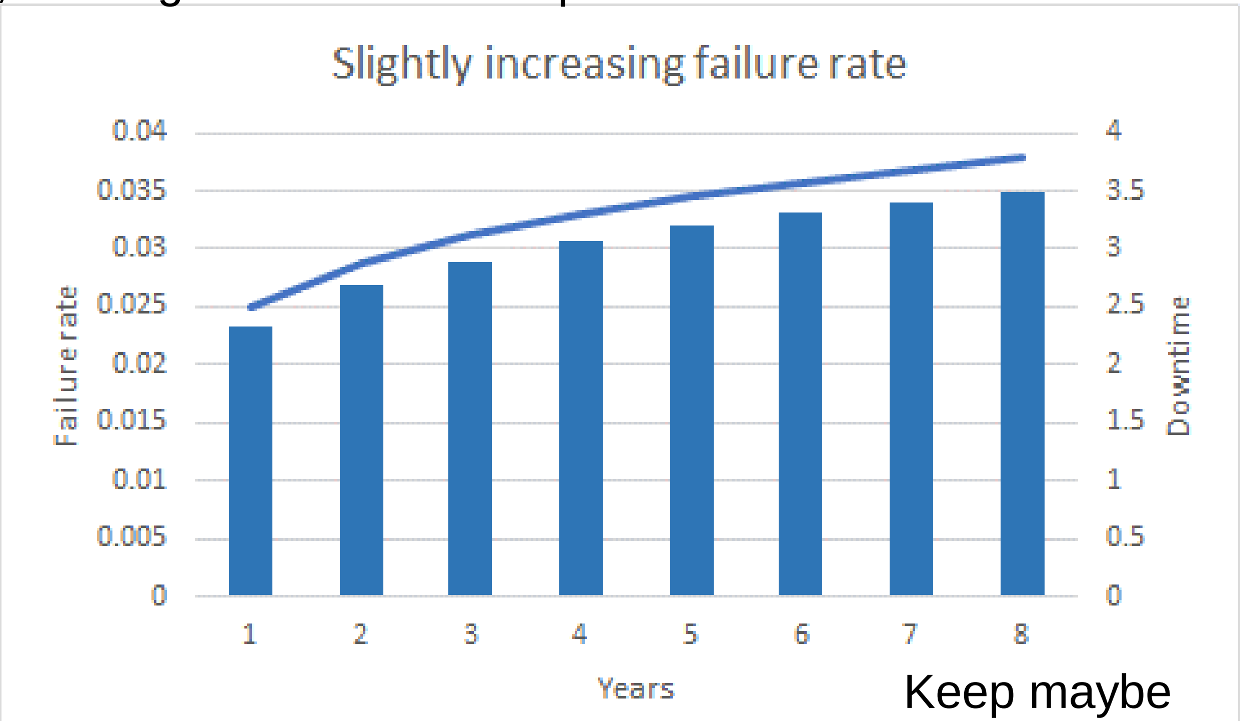
EFFECT OF BATHTUB CURVE

- Demand rate = 0.025, regular lead time 2 weeks, emergency lead time = 48 hours
- downtime = 2 hours, roughly fill rate = 96% , Holding cost 1000 Euros per week



Keep 1 stock

Keep 0 stock



Keep 1 stock

Keep maybe a 2nd stock

CONCLUSIONS

AWARENESS OF VALUE OF INFORMATION

- **Despite** the **imperfectness, demand info** is quite **promising** for practice ➔ **High gain**
- **Imperfectness** of demand info sometimes even less important than **logistics-related parameters** such as **demand rate, cost price, penalty cost, lead time**.
- There are ways to model **demand info**
- Policy: **Dynamic two-sided policy:** Keep stock only when needed for slow moving items
- Future research
  - **Implementing** in practice, also to multiple locations & customers
  - **Heuristic policy** will contribute significantly

FUTURE OF ADI

FOCUS ON COLLABORATION WITH CUSTOMERS & SUPPLIER: BONUS IS SUSTAINABILITY

- **Data sharing ➔ collaboration ➔ distributed / decentralized control towers**
  - **Technical challenges**

- **How** to make this useful for **practice for human?**
  - **Business and social challenges**

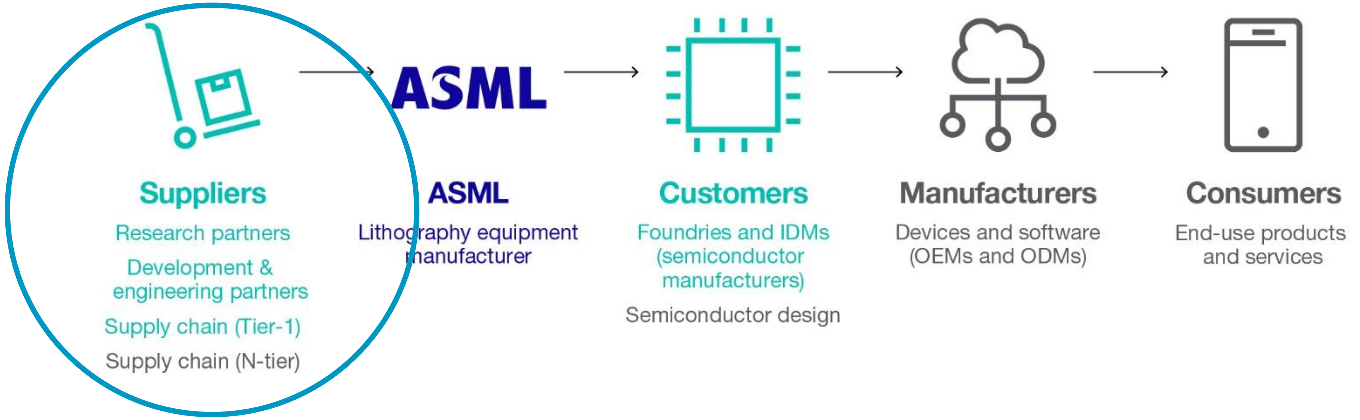
- **Dynamic** policies/solutions to **reduce downtime (resilience)** but also **reduce carbon footprint (sustainability)** ➔ more **data driven** approaches

What **challenges** do you see in using **data?**

INFORMATION SHARING

FOCUS ON SUPPLIERS

- **SME+/ MKBs + manufacturers**



- **More than the half of the high-tech industry**
- **Absorb** the **burden** the **most**
- **Need resilience** the **most**

➔ **CONTROL TOWERS FOR SME+s**

SME+s be active players in their **supply chains**

Thank you for listening!

Questions?